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(Rev.)

FINAL REPORT OF REVERSE OSMOSIS APPRAISAL
PROGRAMS AT CHACO CANYON, NEW MEXICO,
AND PETRIFIED FOREST, ARIZONA

by

G. F. Poole and R. G. Sudak

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NATIONAL PARK SERVICE
WATER RESOURCES DIVISION
FORT COLLINS, COLORADO
RESOURCE ROOM PROPERTY

Prepared under
Contract 14-10-4: 940-165
for the
National Park Service
U. S. Department of the Interior

December 1969

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P.O. Box 608, San Diego, California 92112

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CONTENTS

1. INTRODUCTION	1
2. TEST FACILITY DESCRIPTION	2
Reverse Osmosis Test Unit	2
Chaco Canyon Installation	8
Petrified Forest Installation	8
3. TEST PROGRAM	12
Chaco Canyon	12
Petrified Forest	12
4. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS . .	17
5. CONCLUSIONS	19
6. RECOMMENDATIONS	20

FIGURES

1. Mobile test unit	3
2. Spiral-wound module concept	5
3. Spiral-wound module cutaway	6
4. Module pack assembly	7
5. Unit location at Chaco Canyon, left front view	9
6. Unit location at Chaco Canyon, right rear view	9
7. Unit location at Chaco Canyon, right front view	10
8. Unit location at Petrified Forest, front view	10
9. Unit interior at Petrified Forest	11
10. Unit location at Petrified Forest, right front view	11

TABLES

1. Chaco Canyon operating data	13
2. Chemical analysis at Chaco Canyon	14
3. Petrified Forest operating data	15
4. Chemical analysis at Petrified Forest	16
5. Maximum chemical substances limits	17
6. Fluoride limits	18
7. Maximum substances limits	18

1. INTRODUCTION

This is the final report of appraisal programs conducted at Chaco Canyon National Monument and Petrified Forest National Park for the National Park Service, U. S. Department of the Interior, under Contract No. 14-10-4: 940-165.

The purpose of these appraisal programs was to demonstrate the use of reverse osmosis to provide high quality water from existing well water supplies at the test sites. The goal was to provide water to park users that would meet Public Health Service standards.

The appraisal programs were conducted during the period from October 29, 1969 to November 8, 1969. During this period, adequate data were logged to satisfy the needs of the contract.

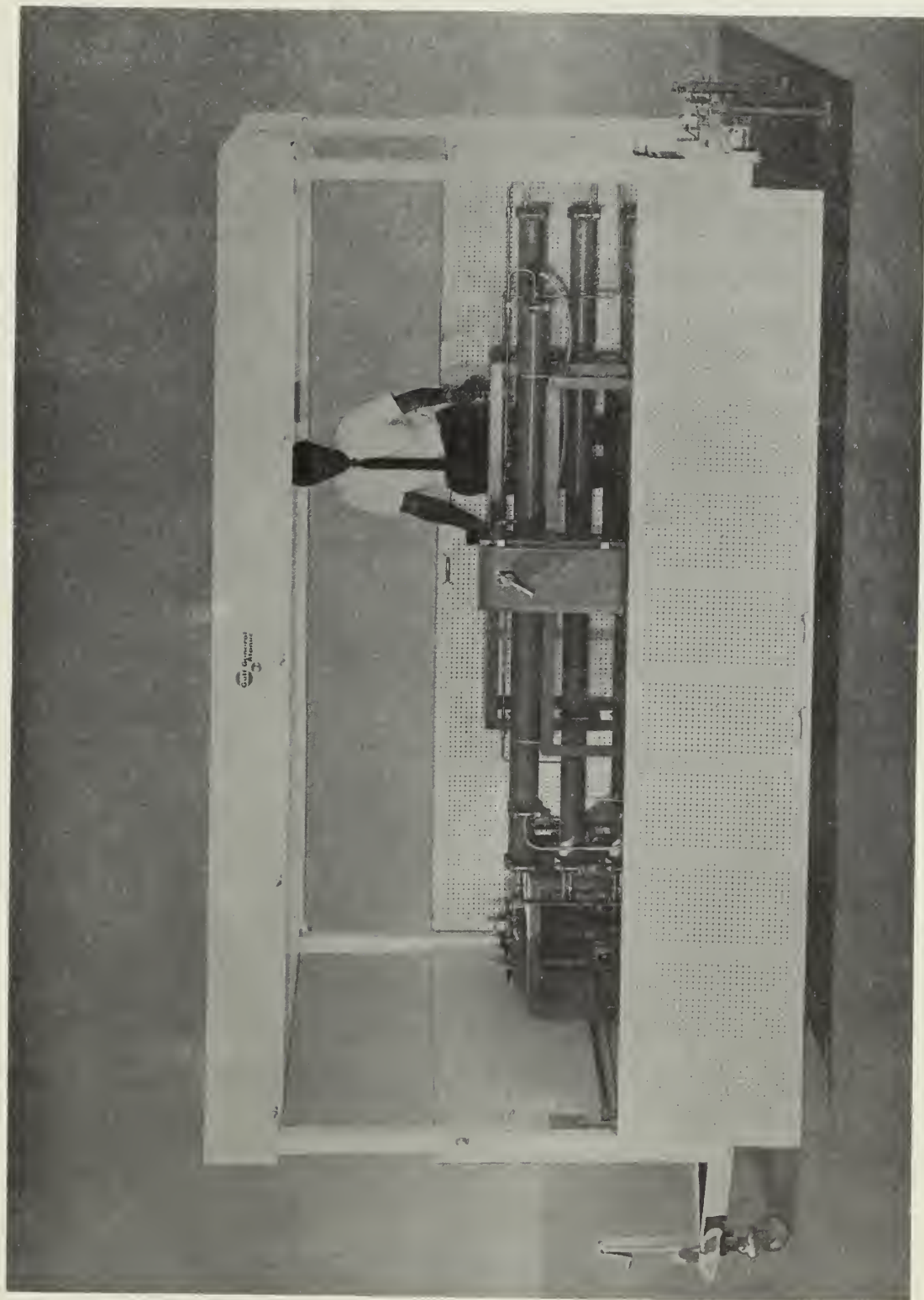
2. TEST FACILITY DESCRIPTION

REVERSE OSMOSIS TEST UNIT

The trailer-mounted Gulf General Atomic reverse osmosis mobile test unit consists of pretreatment equipment, high-pressure pumps, and spiral-wound modules. The test unit is shown in Fig. 1. The test unit has hose connections for feedwater, product water, and brine. Electrical connections for 230 V 3-phase power and 110 V single-phase power are also provided.

The pretreatment equipment is located in the right front corner of the trailer. It consists of 2 chemical-addition pumps, 2 full-capacity cartridge filters (nominal 25 microns) and a pH controller. One chemical-addition pump is used to adjust the feedwater pH to a nominal value of 5, while the other pump is available for addition of other chemicals as required. Operation of the chemical-addition pump is controlled by the pH controller.

Following pretreatment, the feedwater is routed to the pressure vessels containing the submergible pumps. The in-series pumps are capable of delivering 5 gpm at 520 psi total developed head (TDH). The pressurized water is then routed through a pump discharge valve where final adjustment is made to module operating pressure. From there the feedwater is routed to two module pressure vessels with parallel flow. The brine discharge from these pressure vessels is manifolded to the final module pressure vessel. Product water from the three pressure vessels is manifolded and discharged through the bulkhead hose nozzle. Brine from the final pressure vessel is discharged through a backpressure regulator and the bulkhead hose connection. Each of the module pressure



G75088-A

Fig. 1. Mobile test unit

vessels contain 3 Model 4000 ROGA[®] spiral-wound modules with a nominal 50 sq ft of membrane area each. The spiral-wound module is shown conceptually in Figs. 2 and 3, and the modules installed in a pressure vessel are shown in Fig. 4.

The test unit has a nominal capacity of 4000 gpd when operating at a feedwater temperature of 77°F, with 50% of the feedwater recovered as product water. The recovery is limited by the exit brine flow from the last pressure vessel, which should be maintained above 2.5 gpm to mitigate the effects of concentration polarization.

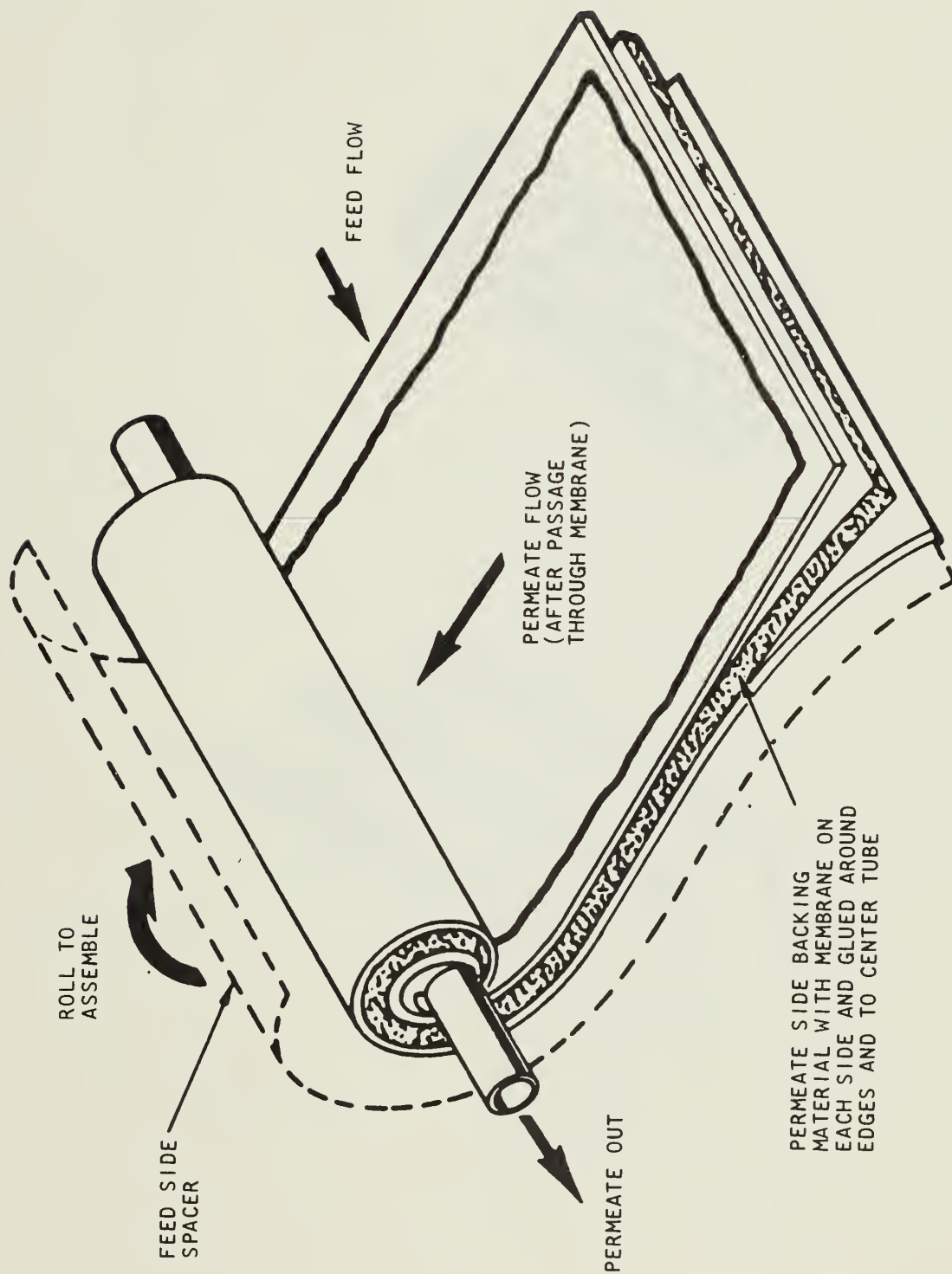
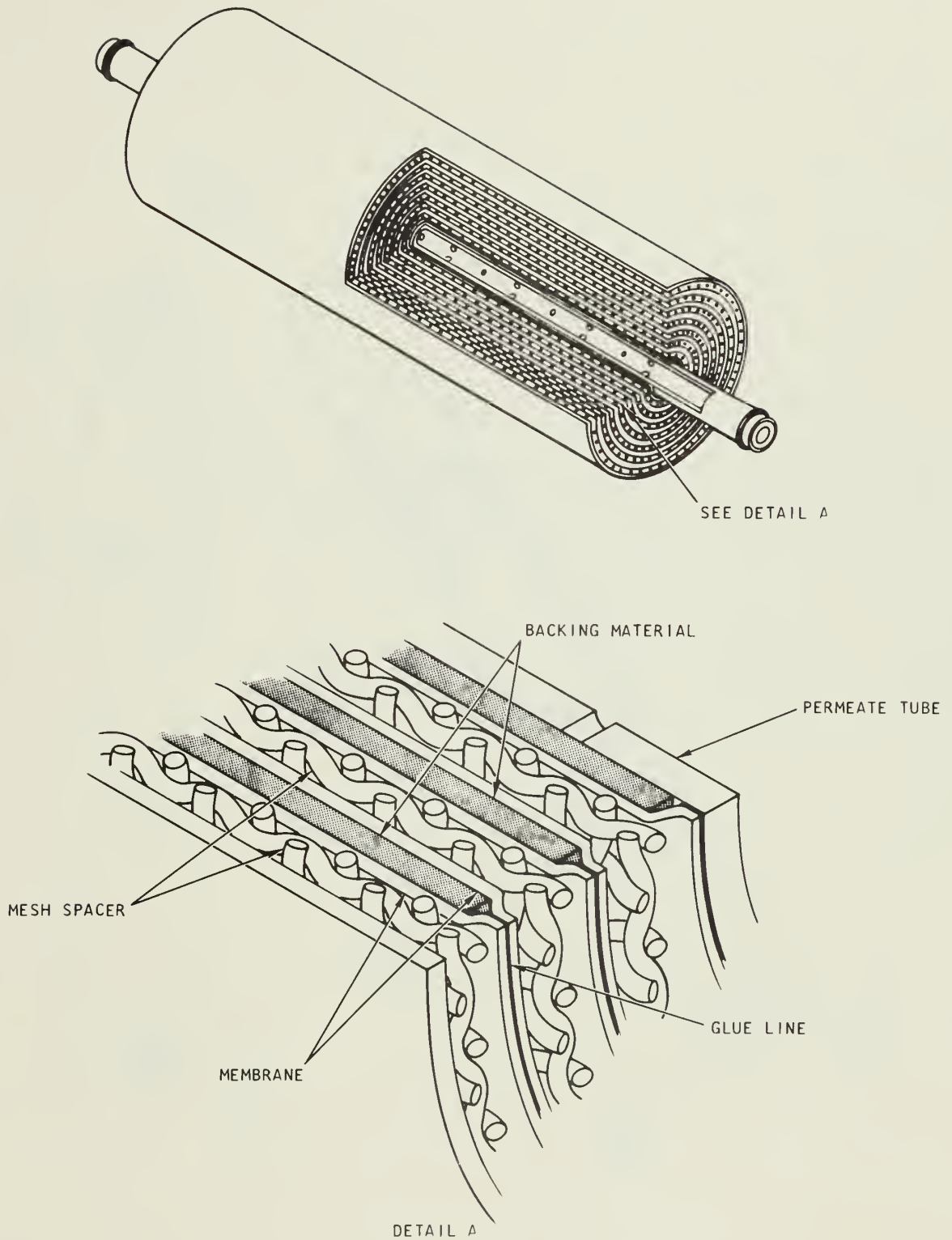


Fig. 2. Spiral-wound module concept

LC59553



LC59405

Fig. 3. Spiral-wound module cutaway

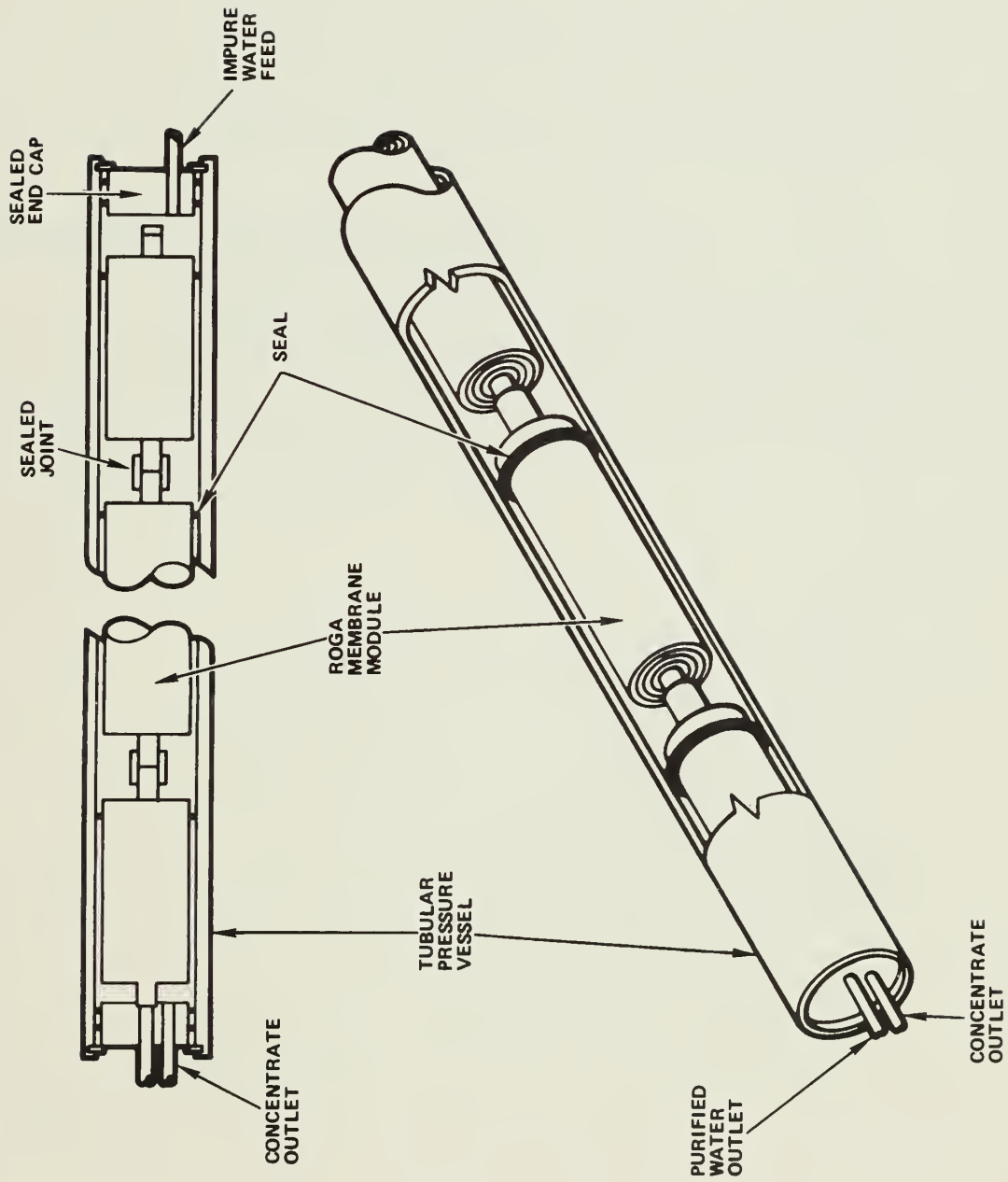


Fig. 4. Module pack assembly

LC42072

CHACO CANYON INSTALLATION

At Chaco Canyon the test unit was located adjacent to the existing well head building as shown in Figs. 5, 6, and 7. The existing water line was disconnected, and well pump discharge was connected directly to the test unit feedwater hose connection. Product water and brine from the test unit were discharged through hoses to a nearby gully for disposal.

PETRIFIED FOREST INSTALLATION

At Petrified Forest the test unit was located in a vehicle wash-rack building as shown in Figs. 8, 9, and 10. Feedwater was taken from the local water supply. Both product water and brine were discharged to the floor drain in the building.



K79230

Fig. 5. Unit location at Chaco Canyon, left front view



K79231

Fig. 6. Unit location at Chaco Canyon, right rear view



K79230

Fig. 5. Unit location at Chaco Canyon, left front view



K79231

Fig. 6. Unit location at Chaco Canyon, right rear view



K79232

Fig. 7. Unit location at Chaco Canyon, right front view



K79233

Fig. 8. Unit location at Petrified Forest, front view



K79234

Fig. 9. Unit interior at Petrified Forest



K79235

Fig. 10. Unit location at Petrified Forest, right front view

3. TEST PROGRAM

CHACO CANYON

In accordance with the schedule agreed upon, the GGA representative and test unit arrived at Chaco Canyon National Monument on the morning of October 29, 1969. It was anticipated that operation of the test unit would begin that day and continue through the evening of October 31. However, the only electrical power available at the site at that time was 220 V single-phase, and 220 V 3-phase power is required for the main centrifugal pumps. The National Park Service obtained the necessary phase converter, which was installed on November 3, 1969, at which time test operations began. Because of this delay, it was mutually agreed that the test program period would be shortened and that no detrimental effect on the data would result.

Operating data are shown in Table 1. Samples of unacidified feed, brine, and product were taken and returned to San Diego for chemical analysis by an independent laboratory. The results of this analysis are shown in Table 2.

PETRIFIED FOREST

When testing at Chaco Canyon National Monument was completed, the test unit was moved to the Petrified Forest National Park. The test unit arrived on site on the morning of November 6 and was positioned in the building; test operations started the same day. Test data are shown in Table 3, while the results of chemical analysis of the unacidified feed, brine, and product are shown in Table 4.

TABLE 1
CHACO CANYON OPERATING DATA

Date	11/4	11/4	11/5
Time	1145	1500	0900
Pressure, psig	420	420	460
Temperature, °F	64	64	67
Feed Conductivity, μmhos/cm	2000	2000	1970
Brine Conductivity, μmhos/cm	4300	4350	3830
Product Conductivity, μmhos/cm	122	107	87
pH	5.0 to 6.2	5.0 to 6.2	5.0 to 6.2
Brine Flow, gpm	2.6	2.6	3.0
Product Flow, gpm	2.7	2.7	2.8
Recovery, %	51	51	48
Rejection, %	97.2	97.6	97.8

TABLE 2
CHEMICAL ANALYSIS AT CHACO CANYON

	Unacidified Feed	Brine	Product
	(mg/l)		
Calcium	1	2	0
Magnesium	1	2	0
Sodium	510	980	19
Potassium	4.2	7.3	0.3
Carbonate	68	0	0
Bicarbonate	683	220	34
Chloride	65	105	18
Sulfate	306	1758	0
Nitrate	0.09	0.11	0.04
Ortho Phosphate	0	0	0
Fluoride	9.5	15	0.98
Iron	0.85	0.38	0.01
Manganese	0	0	0
Boron	0.4	0.36	0.23
Silica	7.0	14	1.4
Total Hardness	6	13	0
Total Alkalinity	670	180	28
Total Dissolved Solids ^(a)	1644	2860	50
pH	9.2	6.1	5.6
Specific Conductivity μmhos/cm @ 25° C	2185	4310	100

^(a) Dried at 185°C.

TABLE 3
PETRIFIED FOREST OPERATING DATA

Date	11/6	11/7	11/7	11/7	11/8
Time	1730	0900	1300	1700	0600
Pressure, psig	495	495	495	495	495
Temperature, °F	64	64	64	64	59
Feed Conductivity, μmhos/cm	1260	1300	1340	1310	1180
Brine Conductivity, μmhos/cm	2680	2620	2590	2600	2480
Product Conductivity, μmhos/cm	76.7	74.9	74.8	74.0	68.1
pH	4.5 to 6.5	4.4 to 6.5	4.8 to 6.4	5.4 to 6.4	5.4 to 6.4
Brine Flow, gpm	2.7	2.8	2.8	2.8	2.8
Product Flow, gpm	2.8	2.8	2.8	2.8	2.7
Recovery, %	51	50	50	50	49
Rejection, %	96.8	96.9	96.9	96.9	97.0

TABLE 4
CHEMICAL ANALYSIS AT PETRIFIED FOREST

	Unacidified Feed	Brine	Product
	(mg/l)		
Calcium	32	52	0
Magnesium	5.8	9.7	0
Sodium	340	600	18
Potassium	4.8	5.9	0.3
Carbonate	0	0	0
Bicarbonate	537	309	24
Chloride	120	175	19
Sulfate	170	1094	0
Nitrate	2.0	3.1	1.0
Ortho Phosphate	0.07	0.14	0
Fluoride	1.2	2.2	0.3
Iron	0.06	0.03	0
Manganese	0	0	0
Boron	0.6	0.8	0.5
Silica	18	26	3.4
Total Hardness (CaCO ₃)	104	170	0
Total Alkalinity (CaCO ₃)	440	254	20
Total Dissolved Solids ^(a)	1060	1850	50
pH	8.0	6.6	5.4
Specific Conductivity, μmhos/cm at 25°C	1550	3200	100

^(a) Dried at 185°C.

4. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS (1962 Revision)

Chemical substances listed in Table 5 should not be present in a water supply in excess of the listed concentrations where, in the judgment of the Reporting Agency and the Certifying Authority, other more suitable supplies are, or can be, made available.

TABLE 5
MAXIMUM CHEMICAL SUBSTANCES LIMITS

Substance	Concentration (mg/l)
Alkyl Benzene Sulfonate (ABS)	0.5
Arsenic (As)	0.01
Chloride (Cl)	250.0
Copper (Cu)	1.0
Carbon Chloroform Extract (CCE)	0.2
Cyanide (CN)	0.01
Fluoride (F)	(See Table 6)
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (No ₃)	45.0
Phenols	0.001
Sulfate (SO ₄)	250.0
Total Dissolved Solids	500.0
Zinc (Zn)	5.0

When fluoride is naturally present in drinking water, the concentration should not average more than the appropriate upper limit in Table 6. Presence of fluoride in average concentrations greater than two times the optimum values in Table 6 shall constitute grounds for rejection of the supply.

Where fluoridation (supplementation of fluoride in drinking water) is practiced, the average fluoride concentration shall be kept within the upper and lower control limits in Table 6.

TABLE 6
FLUORIDE LIMITS

Annual avg of maximum daily air temperatures	Recommended control limits, Fluoride concentrations (mg/l)		
	Lower	Optimum	Upper
50.0 to 53.7	0.9	1.2	1.7
53.8 to 58.3	0.8	1.1	1.5
58.4 to 63.8	0.8	1.0	1.3
63.9 to 70.6	0.7	0.9	1.2
70.7 to 79.2	0.7	0.8	1.0
79.3 to 90.5	0.6	0.7	0.8

Presence of the substances listed in Table 7 in excess of the concentrations listed shall constitute grounds for rejection of the supply.

TABLE 7
MAXIMUM SUBSTANCES LIMITS

Substance	Limit (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Hexavalent) (Cr^{+6})	0.05
Cyanide (CN)	0.2
Fluoride (F)	(See Table 6)
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

5. CONCLUSIONS

In comparing the conditions of the water at the two sites investigated (Chaco Canyon National Monument water conditions listed in Table 2, and Petrified Forest National Park water conditions listed in Table 4) with the recommendations of the U.S. Public Health Service for maximum concentrations of constituents in potable water (listed in Section 4), it is obvious that the water supplies at both locations are substandard. The testing described herein clearly demonstrated that the reverse osmosis process will produce product water from water at the sites that far exceeds the standards of the Public Health Service.

6. RECOMMENDATIONS

Well water presently in use at both Chaco Canyon and Petrified Forest does not meet the standards recommended by the U. S. Public Health Service. As a result of tests conducted at both sites, it has been demonstrated that reverse osmosis can produce water of much better quality than recommended by the Public Health Service.

Since the pH of the feedwater is adjusted to approximately 6.0, carbon dioxide is formed and remains in solution. Some of the carbon dioxide passes through the membrane into the product with a resultant lower pH. Because of the high quality of the product water, it is recommended that the unacidified feed be blended with the product water. The blending will provide several benefits, e. g., raise the pH, stabilize the product water, and provide an increased volume of potable water. Several other methods that can be considered are aeration, degasification, and treatment with limestone or soda ash.

A solution to the problem of brine disposal is also required. At both Chaco Canyon and Petrified Forest, three methods of brine disposal are possible. These are ponding, deep-well injection, and the presently used waste-disposal system.

Deep-well injection has been widely practiced in this country as a method of industrial waste disposal; however, the use of this method has recently come under sharp criticism, and it is discouraged as a method of brine disposal for either location.

In ponding, a basin would be required, and ultimate disposal of the water depends on solar evaporation. Areas that would lend themselves to this method of brine disposal could be made available if so desired.

Another suggested method of brine disposal at both locations is the presently installed waste-disposal systems. In using reverse osmosis it must be remembered that the only addition of dissolved solids to the feedwater is the chemicals employed in pretreatment, i. e., acid for pH control and threshold inhibitors for the prevention of calcium-sulfate precipitation. The product water would be used instead of the brackish water now used and subsequently discharged into the waste-disposal system. If the brine were also discharged into the waste-disposal system, it would be a recombination of the brine and product water and would be essentially the same as the used well water now discharged. Although GGA has not performed a detailed study of the waste-disposal systems in use at either site, it is our opinion that to dispose of the brine this way would present no difficulties and could be considered as an alternative to ponding.

If brine disposal is made through the waste-disposal system, it must be remembered that an additional volume of waste would be discharged. As an example, if 10,000 gpd of potable water is presently required, a reverse osmosis unit operating at 75% recovery would deliver 10,000 gpd of product water and 3330 gpd of brine. Again, based on our limited observations, it is our opinion that this additional waste would present no additional problems.

